NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 855

IMPLEMENTING AN EXCHANGE FROM NITROGEN TO HELIUM IN A LARGE HYPERBARIC CHAMBER

by

Kenneth R. Bondi, D. Douglas Wray and James E. Jordan

Naval Medical Research and Development Command
Research Work Unit M4306.01-8013

Released by:

R. L. Sphar, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

21 September 1977

IMPLEMENTING AN EXCHANGE FROM NITROGEN TO HELIUM IN A LARGE HYPERBARIC CHAMBER

by

Kenneth R. Bondi, D. Douglas Wray and James E. Jordan

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 855

Naval Medical Research and Development Command
Research Work Unit M4306.01-8013

Approved and Released by:

R. L. Sphar

R. L. Sphar, CAPT, MC, USN
Commanding Officer
NavSubMedRschLab

SUMMARY PAGE

THE PROBLEM

During some diving experimental procedures, it is necessary to purge a chamber of a large volume of gas (usually air) and replace that gas with a helium/oxygen mixture. Not only is it desirable to accomplish this exchange as rapidly as possible, but it is also prudent to conserve the expensive purging gas.

THE FINDINGS

This report describes how one hour and 9,000 cubic feet (255 cubic meters) of helium were saved when a large hyperbaric chamber was purged of air. This was accomplished by limiting the degree of mixing of helium with chamber air and thus taking advantage of the ability of a lighter gas (helium) to layer upon a heavier gas (air).

APPLICATION

The findings and suggestions contained herein will allow hyperbaric chamber operators to conserve time and gas when a chamber must be purged with a gas whose density differs significantly from the chamber gas. Experiments designed to study the effects of isobaric gas exchange on animals and man may apply these findings advantageously.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Naval Medical Research and Development Command work unit M4306.01-8013 -- "Saturation Diving Using N_2-O_2 mixtures with HeO_2 Excursions. The present report is No. 1 on this work unit. The manuscript was submitted for review on 13 July 1977, approved on 21 September 1977, and designated as Naval Submarine Medical Research Laboratory Report No. 855.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

A 954 cubic foot (27 cubic meter) hyperbaric chamber at a pressure of 4 atmospheres absolute was purged of a nitrogen/oxygen gas mixture (92.5%/ 7.5%) by flushing with 100% helium. The helium entered the top of the chamber, and the N_2/O_2 exited at the bottom so that the lighter gas layered above the heavier gas. Turbulence was kept to a minimum by turning off the life support system, limiting movement of inside divers, and by utilizing overboard dump masks for the breathing gas. Use of the layering technique allowed the chamber to be completely purged of N_2/O_2 in 55 minutes, using 8,143 ft^3 (230 m^3) of helium.

If the layering technique had worked perfectly at the flow rate used (148 ft^3/ min (4.19 m^3/min.)), it would have taken 26 minutes and 3,816 ft^3 (108 m^3) of gas to rid the chamber of nitrogen. On the other hand, if the incoming gas mixed completely and instantaneously with the chamber gas, it would have taken 117 minutes and 17,316 ft^3 (511 m^3) of gas to bring the chamber nitrogen concentration below 1%. Thus, by avoiding unnecessary turbulence and thereby taking advantage of the layering phenomenon, the best estimate in saving of time and gas is approximately one hour and 9,000 ft^3 (255 m^3) of helium.

In experiments where the environmental gas must be changed from a dense gas to a lighter gas and time and/or gas saving is important, the layering phenomenon may be used advantageously by limiting the degree of mixing.

IMPLEMENTING AN EXCHANGE FROM NITROGEN TO HELIUM IN A LARGE HYPERBARIC CHAMBER

INTRODUCTION

During a recent saturation dive to a pressure of 4 atmospheres absolute (ATA) at the Naval Submarine Medical Research Laboratory, it was necessary to replace a nitrogen/oxygen mixture in a 954 ft^3 (27 m^3) chamber with a helium/oxygen mixture. The objective of the dive was to determine if an isobaric gas exchange at 4 ATA would in any way be harmful to the participating divers.

The divers were dressed in plastic, hooded suits just before the start of the exchange procedure. In this way, nitrogen/oxygen (92%/7%) could be flushed through the suit while the chamber was purged with 100% helium, and on completion of the helium purge and O_2 correction, the divers could make the required step change from the N_2/O_2 of the suit to the He/O_2 environment of the chamber. To minimize the time spent in these suits and to reduce the amount of expensive purge gas, helium was admitted into the very top of the chamber with minimum turbulence and chamber gas exited through the bottom drain of the chamber. The subject of this report is to describe the efficiency of a gas "layering" technique when used to replace a heavier gas mixture with a lighter one in a large hyperbaric chamber.

METHODS

Pure helium from a bank of high pressure cylinders entered the chamber via a pipe 1.5 inches (3.8 cm) in diameter, located at the top, middle of the chamber. Environmental temperature was 70°F. (21°C.). During the first few minutes of helium purge the pipe was pointed so that entering gas would circulate around the circumference of the chamber; but at about the 15th minute of the purge, the pipe was pointed down the long axis of the chamber in an effort to enhance the layering effect. Purge rate of the chamber was 148 ft^3/min (4.19 m^3/min) (all gas volume units are corrected to standard pressure, unless stated otherwise).

Gas exited through a 2 inch (5 cm) penetration reduced to 1 inch (2.5 cm) pipe at the bottom, middle of the chamber. To avoid mixing and turbulence, the life support system was turned off, subject movement was kept to a minimum, and exhalation gases were removed from the chamber by an overboard-dump mask system.

Nitrogen, helium, and oxygen percentages were measured at one minute intervals with a medical mass spectrometer (MEDSPEC SR - 8 Scientific Research Instruments) located outside the chamber. The sampling cannula from the mass spectrometer penetrated the chamber wall via a swagelok tube fitting. The end of the cannula was then attached to a 6 ft (1.8 m) long stick so that one of the subjects could reach, without excessive movement, to all parts of the chamber for spot sampling. During the purge, measurements were taken in the middle of the long axis of the chamber at 1 ft (.30 m) intervals from the top to the bottom deck plates.

RESULTS

The percentage of helium at various levels of the chamber is plotted against purge time in Figure 1 (solid lines). The phenomenon of a relatively pure helium layer pushing the heavier nitrogen/oxygen mixture out the bottom of the chamber may be visualized by the following observations. Virtually no helium reached the 5 ft (1.5 m) level (approximately half way down from the top of the chamber) for the first 13 minutes of purging and virtually none reached the bottom of the chamber until 30 minutes after the start of the purge. Once helium reached a section of the chamber, its concentration rose rapidly to 95% (8-10 minutes for the top and bottom sections, and 20-30 minutes for the high volume middle sections of the chamber).

In less than one hour (55 minutes) the nitrogen/oxygen mixture was purged from the chamber using 8,143 ft^3 (230 m^3) of helium (55 minutes x 148 ft^3 (4.9 m^3)/minute). At this time, the chamber contained 98% helium, the remainder being N_2 and O_2. Oxygen was then bled into the chamber to make the gas respirable.

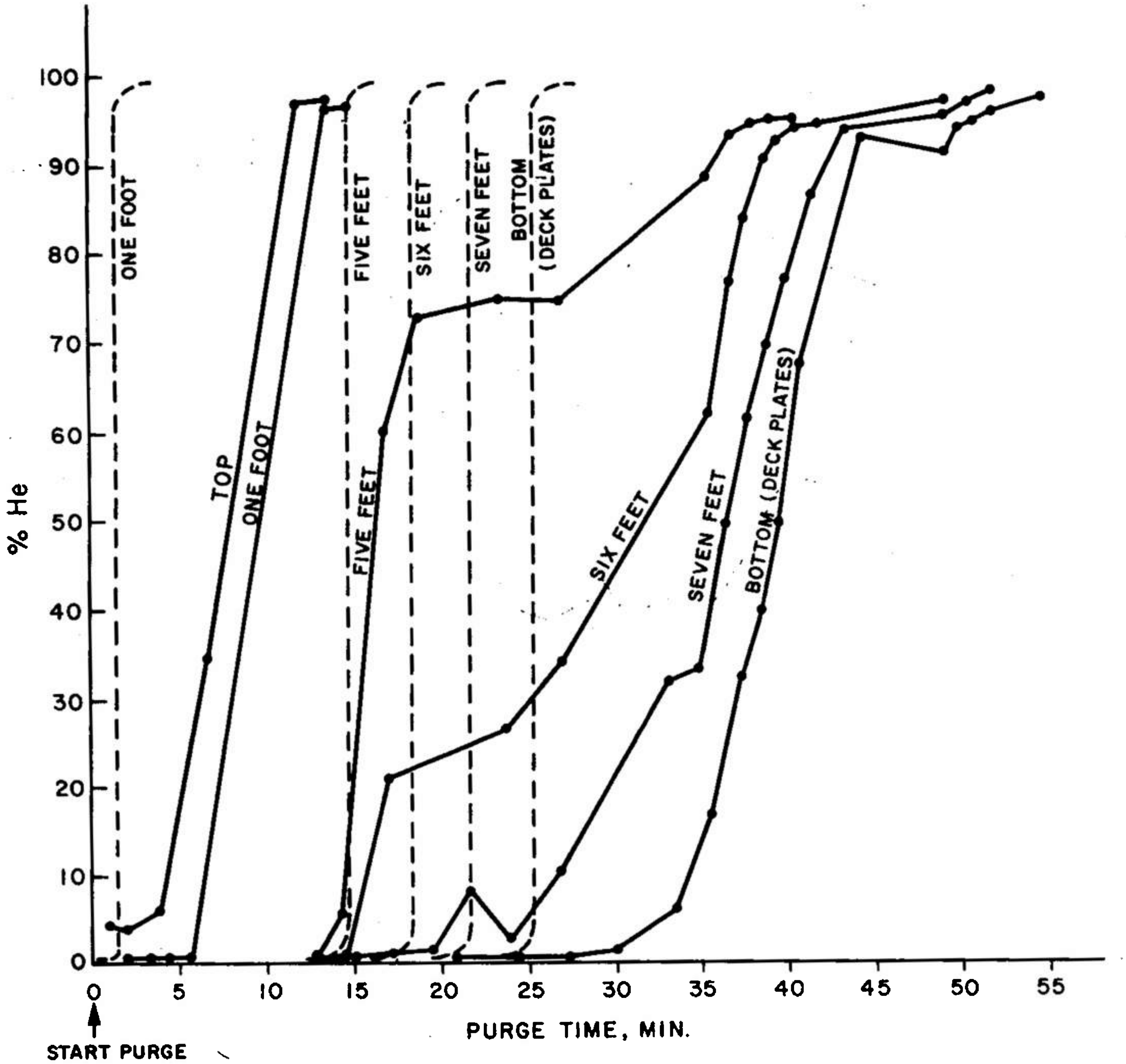


Figure 1. Concentration of helium at various points in the chamber as a function of purge time. The solid lines represent helium measurements taken at a given location in the chamber. A layering effect is recognized by 1) the helium concentration remaining at zero well into the purge time for the middle to lower parts of the chamber and 2) once the helium concentration changes, it rises rapidly towards 100%. If the layering was perfect, the series of dotted lines would have been obtained, the helium concentration rising from zero to 100% in an infinitely short time as the "perfect layer" passed the point of measurement. Total purge time for the perfect situation would have been 26 minutes.

DISCUSSION

The optimum purge rate for the chamber would be one which minimized the amount of gas used while completing the purge as rapidly as possible. This ideal rate would be obtained by increasing flow to just before the start of turbulence (see appendix B). The flow used in this experiment was arbitrarily chosen by the chamber technician and was governed to a degree by the physical constraints of piping, valves, and pressure head from supply cylinders. If, by mass spectrometry measurements, a good stratification was not obtained, the chamber operator would have decreased the flow.

To purge the chamber of nitrogen completely with a flow of 148 ft^3/min (4.19 m^3/min), it would have taken 26 minutes (3,816 ft^3/148 ft^3 $minute^{-1}$) and 3,816 cubic feet (108 m^3) of helium if absolutely no turbulence had occurred (i.e., perfect stratification). On the other hand, if the purge gas mixed completely and instantaneously with the chamber gas, it would have taken 117 minutes and 17,316 ft^3 (490 m^3) of helium to bring the chamber nitrogen concentration to below 1% (see appendix A for calculation). Thus, by minimizing unnecessary turbulence and thereby taking advantage of the stratification phenomenon, the best estimates in saving of time and gas were approximately 1 hr. (117 minutes - 55 minutes) and 9.000 ft^3 (255 m^3) of helium (17,316 ft^3) - 8,143 ft^3). In this experiment we did not know if 148 ft^3 (419 m^3)/minute was the maximum flow obtainable without creating turbulence, and it is likely that more time and gas could have been saved by increasing the flow.

To optimize time and gas usage, one should (1) determine the greatest flow at which there is preservation of a distinct layer,* (2) minimize turbulence by allowing gas to enter in a long multiperforated pipe rather than a discrete orifice and (3) completely restrict the movement of subjects.

---

*The approximate location of the layer at any time may be followed by helium-filled balloons which will "ride" on top of the nitrogen layer, a technique which operators of British chambers have used in the past (personal communication).

In chambers where the environmental gas must be changed from a dense to a lighter gas and time and/or gas conservation is important, the layering phenomenon may be used advantageously by limiting the degree of mixing.

APPENDIX A

WORST CASE CALCULATION (complete mixing)

The N_2 concentration at any time may be calculated using the formula below, which is based on transport kinetics:

$$C_t = C_o \exp \{-[\dot{V}/V]\ t\}$$

where, in this experiment,

C_t = the concentration (volume percent) of N_2 in the chamber at any time (t) (minutes),

C_o = the initial percentage of N_2 in the chamber,

$\dot{V}$ = volumetric flow of purge (standard cubic feet per minute),

V = volume of gas in the chamber (standard cubic feet).

The following is assumed:

1) N_2 in instantaneously distributed throughout the chamber,
2) The volume of gas in the chamber remains constant,
3) The flow through the chamber remains constant,
4) Pressure and temperature remain constant.

Thus, if the desired endpoint were 1% N_2 remaining in the chamber after purge, and the purge gas mixed completely with the chamber gas, the time needed to complete the purge can be determined by using the following data and solving the formula for t:

V = 954 actual ft^3 at 4 ATA, or 3,816 standard ft^3 (108 m^3)

$\dot{V}$ = 148 ft^3/min (4.19 m^3)

C_o = 92% Nitrogen

C_t = 1% Nitrogen

Solving the formula for t,

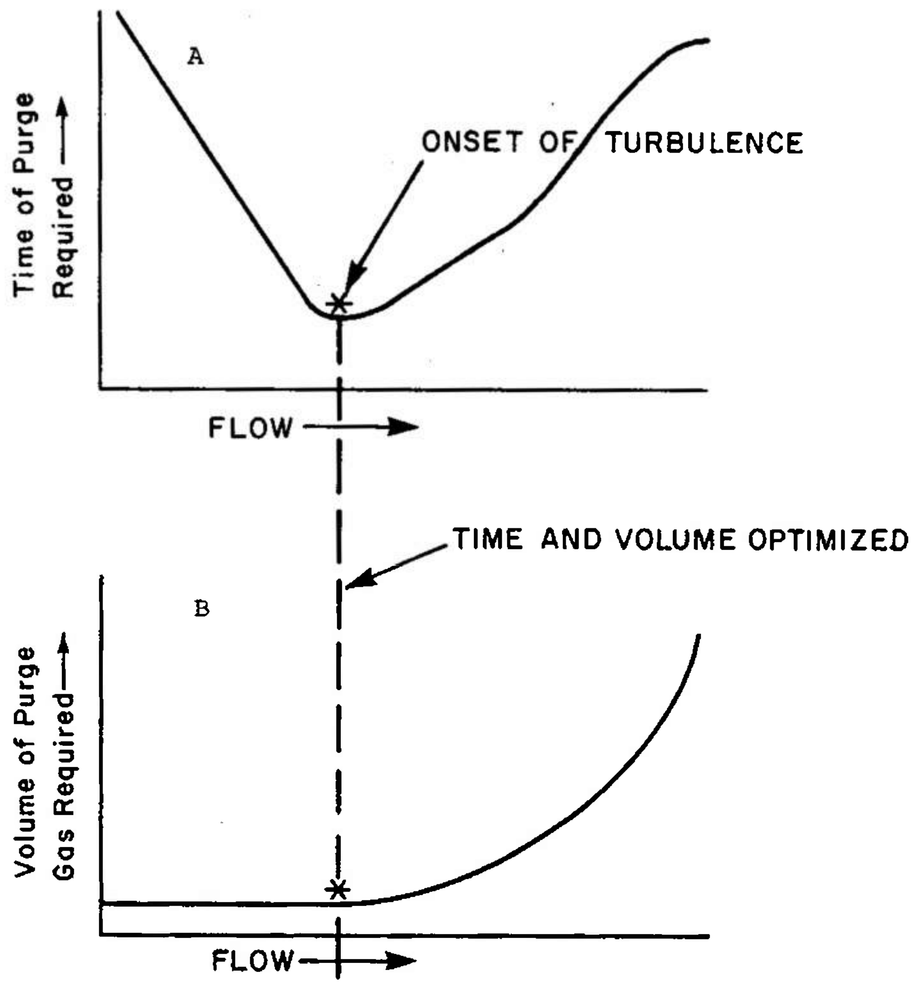
$$t = \left(\frac{V}{\dot{V}}\right) \ln \left(\frac{C_o}{C_t}\right)$$

and substituting the given values, $t = \left(\frac{3,816\ ft^3}{148\ ft^3/min}\right) \ln \left(\frac{92\%}{1\%}\right) = 117$ minutes

The volume of purge gas needed is, $\frac{148\ ft^3}{min} \times 117$ minutes $= \underline{\underline{17,316\ ft^3\ (490\ m^3)}}$

APPENDIX B

For any chamber/piping system one may construct the following graphs:



Graph (a) shows that flow may be increased to reduce time required to purge the chamber to a point where turbulence begins. At this point mixing of the two gases occurs and purge time will increase. Graph (b) shows that as long as a distinct layer exists, the volume of gas required to purge remains constant. At the onset of turbulence, the volume needed starts to increase.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSMRL Report No. 855	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IMPLEMENTING AN EXCHANGE FROM NITROGEN TO HELIUM IN A LARGE HYPERBARIC CHAMBER		5. TYPE OF REPORT & PERIOD COVERED Interim report 6. PERFORMING ORG. REPORT NUMBER NSMRL Report No. 855
7. AUTHOR(s) K. R. BONDI, D. D. WRAY AND J. E. JORDAN		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Box 900 Naval Submarine Base NLON Groton, Connecticut 06340		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS M4306.01-8013
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research and Development Command National Naval Medical Center Bethesda, Md. 20014		12. REPORT DATE 21 Sep 1977 13. NUMBER OF PAGES 5 plus 2 appendix pages
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

chamber; purge; helium; isobaric exchange

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 954 cubic foot hyperbaric chamber (27 m^3) at a pressure of 4 atmospheres absolute was purged of a nitrogen/oxygen gas mixture (92.5%/7.5%) by flushing with 100% helium. The helium entered the top of the chamber, and the N_2/O_2 exited at the bottom so that the lighter gas layered above the heavier gas. Turbulence was kept to a minimum by turning off the life support system, limiting movement of inside divers, and by utilizing overboard dump masks for the breathing gas. Use of the layering technique allowed the chamber to be completely purged of N_2/O_2 in 55 minutes, using

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Item 20. (abstract)--continued

8,142 ft^3 (230 m^3) of helium.

If the layering technique had worked perfectly at the flow rate used (148 ft^3/min (4.19 m^3)) it would have taken 26 minutes and 3,186 ft^3 (108 m^3) of gas to rid the chamber of nitrogen. On the other hand, if the incoming gas mixed completely and instantaneously with the chamber gas, it would have taken 122 minutes and 18,056 ft^3 (511 m^3) of gas to bring the chamber nitrogen concentration below 1%. Thus, by avoiding unnecessary turbulence and thereby taking advantage of the layering phenomenon, approximately 1 hr. and 9,000 ft^3 (255 m^3) of helium was saved.

In experiments where the environmental gas must be changed from a dense gas to a lighter gas and time and/or gas saving is important, the layering phenomenon may be used advantageously by limiting the degree of mixing.